

Description of Three Candidate **Cassini** Satellite Tours

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by John C. Smith

In July of 2004, the Cassini Orbiter and attached Huygens Probe will become the first spacecraft to insert into orbit about Saturn. At the first Titan flyby in November of 2004, the Probe will descend through the atmosphere of Titan taking in-situ measurements of this fascinating moon for the first time. The Orbiter will conduct a four year study of Saturn, its ring system, moons, and magnetosphere with an ambitious scientific agenda. The characteristics of the spacecraft trajectory have a direct influence on the science return. Since the spacecraft trajectory is modified by gravity assists provided by the Saturnian satellites (primarily Titan), the spacecraft trajectory is referred to as the satellite tour. This paper describes three candidate Cassini satellite tours which are indicative of tours currently under consideration for the Cassini mission. The final Cassini tour will not be selected until well after the Earth flyby which occurs in August 1999.

Historically, Cassini tours have been grouped into classes which share common trajectory characteristics; more specifically, those tours which share similar time histories of orbital inclination and local solar time of orbit apoapsis (referred to as orbit orientation). Tour classes are determined solely by the sequence of Titan flybys, since Titan is the only Saturnian satellite massive enough to provide significant gravity assist. The profile characterizing each class can then be fleshed out into any number of complete tours containing flybys of the other Saturnian satellites while also accounting for the many mission constraints and science objectives. Several years of interaction with the Cassini Project Science Group (PSG) has reduced the number of tour classes under consideration from 18 to just 2 (referred to as the T9 and T18 classes).

Particular emphasis was placed on the T18 tour class since it's believed to represent the best compromise between science return and mission operability. The tour design process is a continual tradeoff between science return and mission constraints. Two T18 class tours, referred to as T18-4 and T18-5, are described in this paper and bracket the extremes in this trade space. A third tour from the T9 class illustrates what is probably the upper limit in science return possible for a Cassini tour but which violates more operational constraints than tours in the T18 class. This tour is referred to as T9-1 and is the only complete T9 tour produced to date. A comparison of the three tours illustrates some the tradeoffs involved in the design process and also provides a glimpse as to what the final tour may look like.

The initial and final orientations of all three tours are very similar; however, the trajectories are quite different. Some of the basic tour characteristics are listed in Table 1. Note that the number of Titan flybys varies considerably among the tours as does the AV required. Since T18-4 and T18-5 are in the same tour class, their trajectories are similar, but even within the same class, the differences are striking. The first 1.2 years are common to these three tours and all tours currently under consideration by the Project. The large post-insertion orbit, Probe delivery, two Enceladus flybys, and an important set of Saturn/ring occultations all occur within the first year of the tour. All Project teams judged that the design of the first year accomplished key science objectives while meeting all mission constraints and therefore should not be modified. Therefore, when the tour design is finalized in the year 2000 time frame, only the last 3 years will be subject to modification.

Table 1 Trajectory Characteristics

Tour	Number Titan Flybys	Number Targeted Icy Satellites	Number Nontargeted Icy Satellites <100,000 km Altitude	Number Inclined Orbit sequences (Maximum Inclinations, 0,	Deterministic AV (m/s)	Approximate Deterministic and Statistical AV (m/s)
T18-4	39	7	42	3 (22, 56, 71)	239	425
T18-5	44	7	33	3 (22, 59, 75)	225	433
T9-1	51	9	45	4 (22, 58, 58, 72)	278	534

The primary difference between these three tours is the method used to change the orbit orientation during the second and third years of the tour. Titan gravity assists are used to change the local solar time of orbit apoapsis from the initial dawn orientation (apoapsis over Saturn dawn terminator) to near noon orientation (apoapsis over Saturn sub-solar point). This change in orbit orientation is accomplished by one of two methods. The first is equatorial orbit rotation in which the apoapsis orientation is changed by a series of nonresonant orbits in which the orbit period is alternately increased and decreased and is characterized by near zero orbit inclination. The second method is referred to as a 180° transfer. In this method a series of constant period orbits is used to increase inclination while also increasing orbit eccentricity to the point where both the ascending and descending nodes are at Titan's orbital radius. The true anomaly of Titan in its orbit at which it is encountered by the spacecraft is then changed by 180°, and then orbit inclination is decreased back to near zero. Figure 1 illustrates the geometry of a 180° transfer which rotates the orbit from dawn to midnight orientation. Note that inclination is maximum at the midpoint of the sequence. Both methods begin and end with equatorial orbits and change the orbit orientation by similar amounts. However, the 180° transfer also provides moderately inclined orbits and much lower Titan flyby altitudes which are quite advantageous for many science objectives such as ring, magnetospheric, and Titan observations. The 180° transfer sequence of orbits is more stressful operationally since the time between satellite encounters is much shorter than when equatorial rotation is used.

The three tours discussed in this paper illustrate how the incorporation of various 180° transfer sequences affects the final tour design. The second year of the tour is spent changing orbit apoapsis orientation to the midnight position such that sampling the deep Saturn magnetotail can be obtained. This is accomplished using equatorial rotation in the two T18 class tours and by a 180° transfer in the T9-1 tour. Note from Table 2 that the time between flybys is much lower for T9-1 than either T18-4 or T18-5 during the second year. The higher AV for T9-1 (see Table 1) results because T9-1 uses two 180° transfers during the tour whereas the T18 tours use only one.

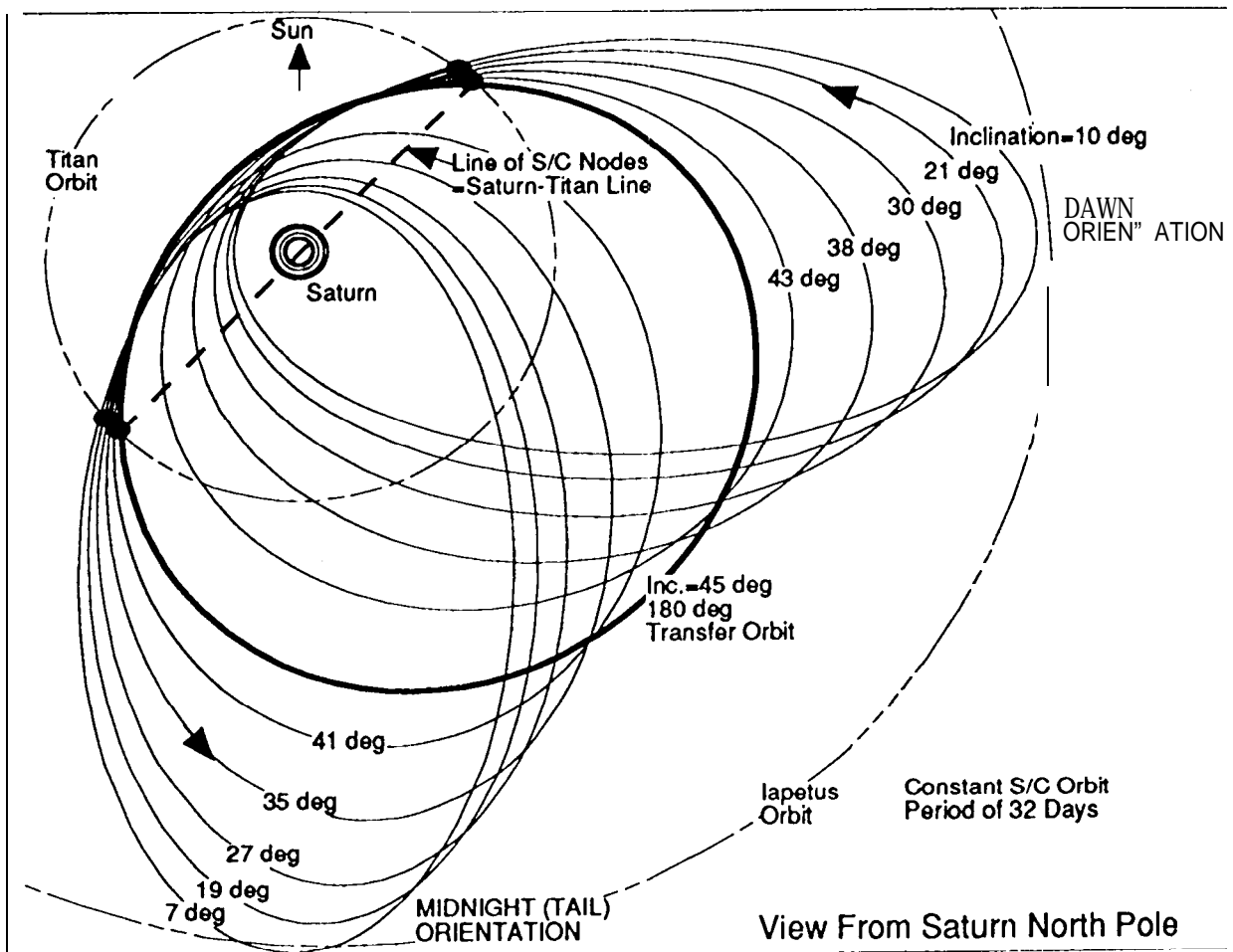
Table 2 Encounter Frequency Comparison

Tour	Average Time Between Satellite Flybys (Days)			
	Year 1	Year 2	Year 3	Year 4
T18-4	48.1	25.5	26.6	31.5
T18-5	48.1	26.5	21.3	24.6
T9-1	48.1	17.2	17.9	25.8

The third year tour objective is to further change orbit orientation from midnight to near noon to set up atmospheric observations and radio occultations at Saturn's higher latitudes. All three tours use a 180° transfer to accomplish orientation change. However, the characteristics of the orbits comprising the 180° transfer sequence are different for all three tours and thus yield differing science return and levels of operational stress (see Year 3 column in Table 2). The fourth year tour objective is to increase orbit inclination to beyond 70° and is accomplished in a similar manner in all three tours described.

The science return is, of course, influenced by much more than just the design of the 180° transfer sequences. The incorporation of additional Saturnian satellites into the tour represents an especially difficult challenge since these satellites must be obtained on orbits which return nearly ballistically to Titan. Constraints on the epochs of maneuvers due to navigation and ground system requirements also represent major challenges to the tour design.

Figure 1 180 deg. Transfer Orbit Geometry



8th AAS/AIAA Space Flight Mechanics Meeting

February 9-11, 1998

Embassy Suites Hotel

Monterey, CA

ABSTRACT DEADLINE: September 15, 1997

The eighth annual AAS/AIAA Space Flight Mechanics Meeting will be held at the Embassy Suites Hotel, Monterey, CA, on February 9-11, 1998. This meeting is cosponsored by the American Astronautical Society (AAS) and the American Institute of Aeronautics and Astronautics (AIAA). The meeting is organized by the AAS Space Flight Mechanics Technical Committee and the AIAA Astrodynamics Technical Committee. Papers are sought from all areas of astrodynamics, including but not limited to:

- Satellite orbital dynamics, perturbation, and stability
- Earth orbital and planetary mission studies
- Trajectory design and optimization
- Analytical, statistical, and numerical aspects of orbit determination and tracking
- Guidance, navigation, and control
- Spacecraft rigid and flexible attitude dynamics, determination, and control
- Dynamics and control of large space structures, modeling of flexible multi-body dynamics, and estimation of distributed parameter systems
- Artificial and natural space debris

Papers dealing with current or future missions are encouraged. Examples of these include Galileo, Cassini, Discovery-class missions, Space Station, Space Station assembly, reusable launch vehicles, Mars Global Surveyor, Mars Pathfinder, NEAR, and Mission to Planet Earth programs.

Papers will be accepted on the basis of extended abstracts of approximately 1000 words. These abstracts should contain a clear and concise statement of the problem addressed and the results obtained as well as a few supporting figures and/or tables. The abstracts should have a cover page that contains the names, affiliations, mail addresses, telephone numbers, fax numbers, and email addresses of all authors, with one author designated as the primary point of contact. The deadline for submitting abstracts is **September 15, 1997**. Letters of acceptance with complete instructions will be sent to authors by November 1, 1997. Authors should then confirm that they will complete the paper for the conference. Final manuscripts are due at the time of the meeting. Note: authors whose papers are not available in printed form at the time of the meeting will not be allowed to present their paper.

In addition, proposals are solicited from prospective session organizers for appropriate special sessions such as panel discussions, invited speakers/papers, workshops, and mini-symposia. Prospective special session, workshop, and/or mini-symposium organizers must submit a proposal consisting of a title, brief description of less than 500 words, list of speakers, and the titles of their presentations, or a list of activities.

Two copies of the abstracts or special session/workshop proposals should be submitted, one each, to the

Technical Chairs, Mr. Jay Middour and Mr. Lester Sackett, by fax or mail at the addresses listed below by September 15, 1997. If possible, in addition, a Microsoft Word file should be submitted by floppy disk or email to each.

Information about the conference, registration, and hotel arrangements may be obtained from the General Chairs listed below. Conference information can also be obtained from the AAS Space Flight Mechanics Committee web site (www.space-flight.org).

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